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Shoreline Change Modeling Using One-Line Models: General Model Comparison and Literature Review

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PURPOSE: The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to document the differences and similarities in the most popular and available shoreline change models employing the one-line approach. One-line shoreline change models calculate evolution of shoreline position by assuming that the beach profile shape remains constant as it advances or retreats and the shoreline evolves to conserve sand along adjacent beaches.

INTRODUCTION: Engineers and scientists have analyzed long term shoreline evolution primarily using (1) measurement and analysis of historical shoreline position, (2) models based on the conservation of sand volume equation (one-line models), (3) coastal morphodynamics models, and (4) physical models (Dean and Dalrymple 2002). Statistical analysis of data (method 1) is the most accurate method to characterize shoreline change, but it does not provide a means to evaluate potential changes to the system as a function of engineering activities (e.g., construction of a breakwater, beach nourishment) or major climate change. Numerical models of the equations of motion, the coastal morphodynamics models (method 3), in simple or more complete forms, require large computational resources and are not well suited to the large spatial and temporal scales over which beaches evolve. Physical models (method 4) are well suited to local analysis but are cost prohibitive to use for very large scales; model-to-field scaling also becomes an issue when attempting to evaluate large areas with a small model. Therefore, the conservation-of-sand-volume approach (method 2), also known as the one-line approach, has remained the preferred model for evaluating shoreline change that could result from anthropogenic or natural changes in the beach system.

The one-line concept is based on the premise that the beach profile shape remains constant as it advances or retreats so that volume change is directly related to shoreline change (Frey et al. 2012). Spatial and temporal variations in gradients in longshore transport drive shoreline advance or retreat. The basic assumptions common to all one-line models are as follows:

- The beach profile shape remains constant.
- The shoreward and seaward vertical limits of the profile are constant.
- Sand is transported alongshore by the action of breaking waves and longshore currents.
- The detailed structure of the nearshore circulation is ignored.
- There is a long-term trend in shoreline evolution.
- There is an adequate sand supply (i.e., an infinite supply of sand is assumed).

Dozens of different models have been developed to simulate shoreline change since the first one-line model was proposed by Pelnard-Considère in 1956 (Dean 2002). For a more detailed summary of the history of one-line theory, refer to Larson et al. (1997). Although many shoreline change

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models have been developed, three have become the standard applied for engineering applications since the 1980s, representing the majority of the capabilities found in other one-line models:

- GENESIS (**GENE**ralized model for **SI**mulating **S**horeline change)
  - Funded by USACE and developed by USACE and University of Lund.
  - GENESIS is currently available in two major versions.
    - A code with an implicit numerical solution scheme.
    - A code with an explicit solution scheme was developed specifically to investigate tombolo formation (GENESIS-T) (Hanson and Kraus 2004).
      - GenCade (**Gen**esis + **C**asc**ade**) (Frey et al. 2012) was developed using this code as a basis.
  - Technical documentation: Hanson (1987); Hanson and Kraus (1989); Gravens, Kraus, and Hanson (1991); Hanson and Kraus (2004).
- UNIBEST (**UNI**form **BE**ach **S**ediment **T**ransport)
  - Funded and developed by Deltares, Inc.
  - Technical documentation: Deltares (2011).
- LITPACK (integrated model for **LIT**toral **P**rocesses **A**nd **C**oastline **K**inetics)
  - Funded and developed by Delft Hydraulics Institute (DHI).
  - Technical documentation: DHI (2009a-d).

Although the major assumptions and fundamental shoreline change equation remain constant in all of the models listed above, each model employs various approaches and approximations to achieve the final result, and each has unique capabilities. The new shoreline change model GenCade (Frey et al. 2012) developed by the USACE extends shoreline change capabilities beyond those previously available. GenCade was developed using the explicit version of GENESIS, called GENESIS-T.

This CHETN will compare GenCade to the three *industry standard* one-line models to document which capabilities are enhanced and help engineers and scientists choose the most appropriate model for each unique situation. This CHETN is not intended to provide a detailed review of the inherent risks in applying a simplified model of shoreline change. The reader is referred to Young et al. (1995) for a comprehensive discussion on the risks of applying one-line models.

MODEL DOCUMENTATION: Each of the four models has professional quality documentation describing the theory and providing detailed instructions on use. Although each model reference is slightly different from the others, none appears to be substantially better in scope, examples, or guidance. Notably, USACE has frozen the development and is no longer maintaining and updating the documentation for GENESIS; current and future USACE investment in one-line model technology is focused on GenCade. Table 1 compares model documentation methods for each model. Documentation for GenCade and GENESIS is openly available online at *http://cirp.usace.army.mil/* and various other sources. Documentation for LITPACK and UNIBEST is generally available from the developers and accessed through a request for a free demonstration license.

Table 1. Available documentation types for evaluated models.				
	GenCade	**GENESIS**	**LITPACK**	**UNIBEST**
User guide	Y	Y	Y	Y
Theoretical documentation	Y	Y	Y	Y
Wiki	Y	Y	N	N
Forum	N	N	Y	N
Website(s)	Y	Y	Y	Y
Training Courses Available with Fee	Y	Y	Y	Y

MODEL INTERFACES: Each of the models has a graphical user interface (GUI) for easier model setup and application. A follow-on report will document the differences during test applications among GenCade, LITPACK, and UNIBEST. Frey et al. (2012) discuss some comparisons between GENESIS and GenCade. Szmytkiewicz et al. (2000) compared GENESIS, UNIBEST, LITPACK, and Sand94. Sand94 was not evaluated in this CHETN. Models selected for comparison were limited to provide a more concise comparison to GenCade. Unlike the others, GENESIS has many different interfaces available, but the official current release is supported through CEDAS by Veri-Tech, Inc[1]. Table 2 provides the name of the current GUI for each model.

Table 2. Graphical user interfaces for evaluated models.				
	GenCade	**GENESIS**	**LITPACK**	**UNIBEST**
Graphical User Interface	SMS	CEDAS	MIKE Zero	UNIBEST-CL+

UNIBEST and LITPACK are integrated packages, meaning that the systems are based on a series of modules. Both are coupled with a cross-shore profile development module that allows for estimation of storm-induced profile (cross-shore) response in addition to longshore processes. GenCade and GENESIS are not coupled with a cross-shore profile response tool; however, SBEACH (Larson and Kraus 1989) was developed for this purpose and is housed in the CEDAS GUI.

MODEL TECHNICAL DESCRIPTION: This section describes the technical capabilities of each model. Most subsections include a table comparing the models[2]. Capabilities that could not be conclusively assessed through literature review were labeled NA (Not Available). Those capabilities will be assessed in a future CHETN documenting comparative testing of each model.

Model Grid and Domain. Each of the four models uses a 1D grid. GenCade, GENESIS, and LITPACK use a linear grid with shoreline position specified as some scalar value at each grid point. GenCade allows for variably sized grid cells to help decrease run time while allowing increased resolution around structures. UNIBEST uses a curved grid. The shoreline position is specified as a scalar quantity normal to the curved grid at each grid point. Each of the models has a 1D grid and operates by making calculations at sequential time-steps. At each time-step, a model calculates the longshore transport at each grid cell, and then for each grid cell, it sums up

[1] Veri-Tech information can be accessed here: http://www.veritechinc.com/
[2] GENESIS results include both the standard and T (tombolo) versions.

all the contributions and losses from/to adjacent cells, plus all other sources and sink terms to calculate a shoreline change in that cell for that time-step.

One consequence of the simplified approach of using a one-line model is that the shoreline shape tends to evolve towards the original shape of the grid. For the linear grids, the shoreline shape tends to evolve towards a straight line during the simulation. Likewise, shorelines using a curvilinear grid tend to evolve towards the original shape of the curved grid. Although not a fundamental assumption, one-line models tend to perform best over regions that are relatively straight. Complex shorelines are often formed over geological time scales by processes not included in one-line models, so the fact that one-line models perform better over straight regions is not surprising. The curvilinear grid provides one means to address this problem. GENESIS and GenCade address this problem through application of a regional contour. The regional contour is a mathematical method to force the shoreline towards some predefined shape instead of a straight line. LITPACK does not include a regional contour function.

Waves. Waves are the primary driver of longshore transport, the main process responsible for shoreline change in a one-line model. In GenCade and GENESIS, wave parameters at breaking are used to calculate longshore transport. In LITPACK and UNIBEST, wave parameters at the seaward end of the specified cross-shore profile are input to the 2D (cross-shore and vertical) model of waves, currents, and transport. LITPACK and UNIBEST apply a model of shoaling and refraction to transform waves to breaking; the approach in Battjes and Janssen (1978) is used to calculate wave dissipation across the surf zone. Linear and non-linear models of waves are applied to estimate hydrodynamics for transport calculation (DHI 2009d). Table 3 lists wave capabilities included in each model. A major difference between UNIBEST and LITPACK compared to GenCade is the capability to include wave-current interaction directly, a process not captured in GenCade except through modification of empirical transport coefficients. Wave processes specific to structures will be described in the Structures section.

Table 3. Waves in evaluated models.

Waves	GenCade	GENESIS	LITPACK	UNIBEST
Internal wave model	Y	Y	Y	Y
Coupled spectral wave model	N*	Y	N*	NA
Wave-current interaction	N	N	Y	Y

* Spectral wave model coupling to the shoreline change model is currently under development.

Longshore Sediment Transport. Shoreline change in one-line models is driven by gradients in longshore transport, making transport the most important process calculated. GenCade and GENESIS both use the same basic routine for calculating longshore transport. Breaking wave height and angle are first calculated, providing the forcing for the transport equation. Then that information is used in a variant of the CERC formula (USACE 1984). The empirical formula includes terms that relate breaking wave angle and height, longshore currents, and the gradient in wave height to longshore transport of sand (Frey et al. 2012; Hanson and Kraus 1989).

LITPACK employs a fully deterministic approach to estimate longshore transport. The same basic equations applied in other DHI models are applied with wave and current forcing on the 2D profile (across-shore and vertical) at each cross section defined. The benefit of this approach

over a semi-empirical energy flux approach is primarily that the shape of the beach profile is implicitly included in analysis. So, theoretically, transport over a barred beach profile could be more accurately represented in the model. This approach also allows for the inclusion of time-varying water level on transport rate calculation. The main drawback is finding the data for accurate validation of the results. The argument has been made that model validation based on observed shoreline change, which is usually the case for shoreline change models, is not at the proper spatial and temporal resolution to accurately represent the cross-shore formulation. Thus, shoreline change validation essentially smoothes over the added benefit of higher resolution afforded in the cross-shore formulation (Szmytkiewicz et al. 2000). Detailed discussion of the various algorithms used to calculate sediment transport can be found in DHI (2011d).

UNIBEST calculates longshore transport based on rigorous calculation of transport across a cross section from sea to the dune similar to LITPACK. Unlike LITPACK, UNIBEST also has the option of applying a CERC formula approach (similar to GenCade, but excluding the term based on the gradient in breaker height). Detailed discussion of the eight algorithms available to calculate sediment transport can be found in Deltares (2011).

Another difference is that UNIBEST and LITPACK include sediment transport formulations that allow for non-uniform sand gradations and shingle beaches; GENESIS and GenCade do not. Even though UNIBEST and LITPACK calculate transport across a sectional profile, the assumption that the profile remains in equilibrium still holds (i.e., the profiles shape is not changing in time).

Structures and Location-Specific Adjustments. Shoreline change models are often developed to evaluate the influence of constructing or removing/modifying existing structures on shoreline change. Structures that can be modeled in each system are listed in Table 4, in addition to some specific attributes of some structure features.

Table 4. Structures in evaluated models.

	GenCade	GENESIS	LITPACK	UNIBEST
Breakwaters	Y	Y	Y	Y
Beach fill	Y	Y	Y*	Y*
Diffracting groin	Y	Y	Y	Y
Nondiffracting groin	Y	Y	NA	Y
Jetties	Y	Y	Y	NA
Seawalls/revetments	Y	Y	Y	Y
T-head groins	Y	Y	NA	NA
Salients/tombolos	Y	Y	Y	Y
Trench	N	N	Y	N
Detached breakwater transmission	Y	Y	N	NA
Time dependent breakwater transmission	Y	Y	N	NA
Water level dependent wave transmission	Y	Y	N	NA
Wave reflection from structures	N	N	N	N
Wave diffraction around structures	Y	Y	Y	Y

*Beach fill added as a source

Wave diffraction in the presence of structures is a key process included in the models. Although UNIBEST does allow for the influence of diffraction within the model, it does not calculate diffraction within the code; the wave height reduction factors resulting from diffraction must be calculated externally and then supplied to the model through a table. The UNIBEST manual (Deltares 2011) recommends application of the diffraction diagrams in the Shore Protection Manual (Headquarters, USACE 1984) if a suitable wave model is not applied.

Lateral Boundary Conditions. Both lateral ends of the 1D domain require boundary conditions. The simplest is to fix (pin) the shoreline position so that no change is allowed; all of the evaluated models include this option. LITPACK seems to have the fewest options allowing only pinned boundaries, and UNIBEST adds a few slight modifications. Table 5 lists lateral boundary conditions for each model.

Table 5. Boundary conditions for evaluated models.

	GenCade	GENESIS	LITPACK	UNIBEST
Moving boundary	Y	Y	N	N
Pinned boundary	Y	Y	Y	Y
Gated boundary	Y	Y	N	N
Constant shoreline angle	N	N	N	Y
Constant transport rate	N	N	N	Y
Variable transport rate	N	N	N	Y

A brief definition of the boundary conditions listed in Table 5 is provided below:

- Pinned: Shoreline position is specified as constant at the initial shoreline position.
- Moving: The shoreline position is specified to move at a constant rate from the initial shoreline position.
- Gated: A gated boundary is usually specified at a groin. The gated boundary condition allows the net transport into or out of the model domain to be *tuned* to align with external information derived, for example, from a sediment budget.
- Constant shoreline angle: The angle of the shoreline is fixed at the initial shoreline angle.
- Constant transport rate: User specifies a constant longshore transport rate.
- Variable transport rate: User specifies a longshore transport rate that varies in time.

Inlets. The most significant feature included in GenCade, not included in the other models discussed, is the capability to include inlets within the model domain. The other models can be used adjacent to inlets, but each inlet requires a new domain, and any processes related to the inlet must be added through sources, sinks, or boundary conditions. GenCade allows the user to specify inlets within the domain by adding internal boundaries within the model. The inlet module includes bypassing with structures or without, specification of attachment bar locations, and allows for specified inlet volume reduction in time (e.g., dredging and recharge). A classic case that this feature enables is evaluation of dredging the ebb shoal for beach nourishment. GenCade calculates the rate of recharge of the inlet shoals, impacts to adjacent beaches, and the performance of the placement within a single domain. Table 6 lists some inlet features.

Table 6. Inlet features in evaluated models.				
	GenCade	GENESIS	LITPACK	UNIBEST
Inlet bypassing within the grid	Y	N	N	N
Inlet shoal/feature sediment balance	Y	N	N	N
Inlet shoal dredging	Y	N	N	N

Variable Parameters. Various parameters and model features that were fixed in initial model versions have been modified through time to vary alongshore to help extend the range of applicability of one-line models. Because of the coarse nature of one-line models, application of parameters that vary alongshore should be approached with care. Table 7 lists some parameters that vary in the longshore direction in each model. Varying water level in GenCade and GENESIS only influences transmission at detached breakwaters.

Table 7. Variable parameters in evaluated models.				
	GenCade	GENESIS	LITPACK	UNIBEST
Variable depth of closure	N	N	Y	NA
Variable empirical transport coefficients	N	N	NA	NA
Variable resolution grid alongshore	Y	N	N	N
Time- and space-varying source/sink	Y	Y	Y	Y
Variable cross-shore profile	N	N	Y	NA
Variable grain size	N	N	Y	NA

Other Model Features. Table 8 lists some other model features not previously discussed. Wind driven transport can be added to all models through external calculations; the entries in this table for wind-driven transport refer to an internal calculation. The offshore contour provides the orientation of the bottom contour for the wave transformation calculation by the wave model. The combination of the regional contour and inlets in GenCade allow for modeling of greater regional stretches. Although UNIBEST does not use a regional contour, it applies a curvilinear grid that can be used to model more complex coastal areas generally consistent with longer regional distances.

Table 8. Other included processes, modules, or features in evaluated models.				
	GenCade	GENESIS	LITPACK	UNIBEST
Direct provision for changing tide level	Y	Y	Y	Y
Tidal/other non-LST currents	Y	Y	Y	Y
Offshore contour	Y	Y	Y	NA
Wind-driven transport	N	N	N	Y
Regional contour	Y	Y	NA	NA

CONCLUSIONS: This CHETN presents a comparison of capabilities included in four numerical models of shoreline change: GENESIS, LITPACK, UNIBEST, and GenCade. A second CHETN is planned to conduct simple test cases with each model and document ease of use, GUI features, apparent accuracy, and limitations to help guide users of shoreline change models.

Results indicate that all models represent the same major processes driving shoreline change with many small variations in approaches or capabilities. The major differences in capabilities noted are listed below:

- GenCade is the only model that allows inclusion of inlets within the model domain and includes the impact of inlet processes and dredging on adjacent shorelines.
- UNIBEST and LITPACK include a more rigorous calculation method for longshore transport. Calculations are conducted on a 2D grid (cross-shore and vertical).
- UNIBEST applies a curvilinear grid instead of linear. GenCade and GENESIS address the same issue through addition of a regional contour. LITPACK does not include either option.
- UNIBEST does not calculate diffraction internally.

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